Io's thermal anomalies: Clues to their origins from comparison of ground based observations between 1 and 20pm

Diana L. Blaney, Glenn J. Veeder, Dennis L. Matson, Torrence V. Johnson, Jay D. Goguen

NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

John R. Spencer

Lowell Observatory, Flagstaff, Arizona

Abstract. Io's thermal emission for 1995 from eclipse photometry at 2.2 µm; broad band radiometry at 4.8 µm, 8.7 µm and 20 pm; and in eclipse imaging between 1.7 and 5 µm are compared. The variability of thermal emission from Io at wavelengths between 1-S µm (Silverstone *et al., 1995;* Spencer *et al.*, 1 *WI')* is in agreement with the expected variability based on the 13 year record presented in Veeder *et al. (1994)* and Goguen *et al.* (1996). We conclude that 1995 was typical for Io, in terms of overall observed variability in the volcanic sources. Detailed comparison of data from Goguen *et al.* on Aug. 24 and Spencer *et al.* on Aug. 26 provides evidence of a high temperature eruption that produced a larger, cooler region over the course of two days. The observed frequency of occurrence of high temperature events, the linking of high and lower temperature thermal anomalies, and the observed stability of volcanic regions since Voyager suggests that high temperature silicate eruptions could support the entire observed population of cooler temperature anomalies. It may be more productive to consider sulfur flows on Io in the context of remobilization of existing sulfur deposita.

I. Introduction

Three broad classes of infrared observations have been used to study Io's volcanoes from the Earth.

Disk integrated radiometry (4.8 µm to 20 µm)

The relatively high temperatures of volcanic thermal anomalies produce distinctive thermal spectra. This allows the flux from the anomalies to be distinguished from reflected sunlight at 5 µm and from background thermal emission from non-volcanic regions at longer wavelengths (Matson *et* al. 1981, Veeder *et* al. 1994). The contribution from even relatively small volcanic spots (radii of -1-2 km to 100's of km) can be determined if their temperatures are greater than about 180 K. Hotter spots are detectable at smaller sizes. The background comes from 'normal' daytime surface temperatures of 100-120 K. Calculating the amount of multi spectral 'hotspot' flux required to match observations taken at different sub-Earth longitudes (as Io orbits Jupiter) yields model areas and temperatures of the volcanic sources and their distribution in longitude. Latitude information must come from other techniques such as Voyager and Galileo observations, Disk integrated radiometry has been carried out over the last 13 years (Veeder *et al*. *1994).* Thermal anomalies with model temperatures ranging from 140 K to 800 K are used to fit these data. These data show that there are high surface temperatures (>500 K) somewhere on Io whenever observations have been made (Johnson *et al.,* 1984; Veeder *et al.,* 1994, Goguen *et* al., 1996). In addition, "outbursts" (short lived enhancements in short wavelength flux) imply large eruptions of high temperature material (Johnson *et al.* 1988, Veeder *et al.* 1994, Blaney *et al.* 1995).

Disk integrated eclipse observations (1.5 -5 μm)

When Io is in Jupiter's shadow reflected sunlight is not present in the observed flux. This allows relatively straightforward modeling of the remaining flux, which comes from volcanic areas. Weaker sources of volcanic thermal emission that cannot be recognized in the presence of sunlight can be detected. This method is sensitive to smaller areas with higher temperatures. This technique was first used by Morrison and Telesco (1980). Silverstone *et al. (1995)* and Spencer *et al.* (1997) have reported numerous eclipse observations at wavelengths between 1.7 and 5 μm. The principle limitation of this method is that it only provides information for Io's Jupiter facing hemisphere, and cannot determine source position elsewhere.

Direct infrared imaging during eclipse and Jupiter occultations (1.7 μm to 4.8 pm)

The advent of two-dimensional imaging arrays sensitive in the 1 to 5 μm spectral region has allowed ground bawd telescopes to detect and locate sources in both latitude and longitude to accuracies of several hundred kilometers. Spencer *et al.* (1990,1992,1994,1997) used this technique to identify at least one new long-lived feature (tentatively named Kanehekili) and to study the variability of volcanic features on the Jupiter-facing hemisphere. However, large (>~100 km) volcanic features with 'warm' temperatures (<-300 K) are not easily detectable at these short IR wavelengths.

Although each of the above methods individually has strengths and weaknesses, combining information from several of them can provide a more complete view of Io's volcanic emission sources. In this paper, we study and compare these three types of observations which were made just prior to the arrival of the Galileo spacecraft during the 1995 apparition of Jupiter at wavelengths between 1.7 and 20 μm. The data sets consist of radiometry from 4.8 to 20 μm (Goguen *et al.* 1996), eclipse photometry at 2.2 μm (Silverstone *et al. 1995),* and infrared imaging between 1.7 and 4.8 μm (Spencer *et* al. 1997). This wavelength coverage allows the identification of thermal anomalies ranging in temperature from < 200 to 1500 K.

II. Io Observations in 1995

In 1995, fourteen clear nights resulted in relatively complete longitude coverage of Io at 4.8 μm, 8.7 μm, and 20 μm (Goguen *et* al., 1996). The data are shown in Figure 1. We used the method of Veeder *et* al. (1994) to model these data with a fixed number of hotspots (of appropriate radii and temperatures) to match the shapes of the light curves at all wavelengths shown, Later we will use these radii and temperatures (see Table 1) to model the flux from 10 at all wavelengths.

June 11 to 16, 1995 UT was a period when all observers reported relatively low source strength (open squares). The August 17 to 24, 1995 UT observing period (solid-circle data) shows good agreement with the June data except between longitudes > 270° and <40° where the 4.8 μm flux is roughly a factor of two greater. Enhanced emission was also seen at 8.7 pm. On the basis of total emission levels, 1995 appears to have relatively typical activity and emission levels within the ranges previously observed (see Veeder *et al.* 1995). However, a notable feature of the Aug. 95 data is that a hot spot at a new location is required.

Table 1 shows the areas, temperatures, and locations of the hot spots needed to match the June 1995 Goguen *et al.* data. (Figure 1). The model for the June data uses the same hotspot set as for the previous year and it required only relatively small adjustments in the assigned temperatures and areas. In August, the changes at 4.8 μm on the Jupiter facing longitudes could not be tit **by merely varying the emittance levels in the model's suite** of hot spots which had served to model the previous 12 apparitions.

The radiometry data for August 24 UT (3 10° -350° W) were taken just 1 orbital period prior to the August 26 UT observations *reported* by Spencer et al. (1997) in which they identified six high temperature regions on Io's Jupiter-facing hemisphere. An increase in flux at these longitudes was observed about 1 month earlier on 20 July UT by M. Silverstone (1995). The shape of the radiometry light curve is best fit by including a new spot at the location of Spencer's spot 9507A (Lat 22° N, Lon 351" W). Other sources such as 9508A (Lat 32° N, Lon 20" W) and Loki (Lat. 13°, Len. 309") are too far east or west to match the shape of the light curve. A two component model is fit to the data in Figure 1 using sources with model radii of 2.2 and 220 km with temperatures of 1500 K and 200 K respectively. The 1500 K temperature is not uniquely determined, but a source with a temperature > 1000 K is required. The model in Figure 1 does not agree with data taken on Aug. 21, 1995 (solid circles below the model line), suggesting that the high temperature part of this eruption started after these observations were made. The large cool area may be an older flow that was already cooling, perhaps related to the Silverstone *et al.* July observation.

To investigate the hypothesis that the different observational techniques are sensing the same suite of volcanic events, we compared the 1995 radiometry data, the imaging data of Spencer *et al.* (1997) and the 2.2 μm eclipse observations of Silverstone *et al.*, (1995). These observations are plotted in figure 2 after being converted to effective integrated disk magnitudes for the thermal emission component using the IRTF fluxes for Vega (after Hanner *et al.* (1992), Beckwith *et al.* (1976), Hanner *et al.* (1984)). Dotted lines connect data taken during the same observation sequence.

111. Comparison of the data sets

Variation in Emission Levels

We used the modeled hotspot characteristics given by Veeder *et al. (1994)* and those derived from the Goguen et al. (1996) data in Table 1 to calculate the 1-5 μm flux for the 350° W hemisphere for each apparition in Figure 2. These are reasonable estimates of what a 1-4 μm observer would have measured at the time corresponding to the Veeder *et al.* and Goguen *et al.* observations.

The 1995 eclipse data fall well within this range. All of these fluxes are lower than the fluxes expected during the times of higher power "outbursts", The August 1995 emission was significantly enhanced at short wavelengths, but is well within the range expected from previous apparitions.

Aug 24-Aug 26 Comparison

There appears to have been a significant change in emission characteristics from Aug. 24 to Aug. 26. On Aug. 24, the 4.8 μm emission was 0.05 $Wm^{-2}\mu m$ (Goguen *et al*. 1996). Two days later Spencer *et al.* observed a 4.8 μm flux of -0.03 $Wm^{-2}\mu m$, a 40% *decrease. The* model for the 24 Aug. data predicts a much higher flux at 1-4 μm than Spencer *et al.* measured on the 26th. The type of change required is suggested by examining the model spectrum for the 1990 outburst in Figure 2. The 24 Aug. model resembles the early, high temperature phase (1990a) while the 26 Aug. data more closely parallel the spectrum modeled for the 1990b curve (end of the night) implying cooler temperatures. A reasonable (but non-unique) interpretation is that the Aug 24 and Aug. 26 observations are due to a new eruption which was first seen while it was still hot and then observed again two days later after it had cooled to a lower temperature. If this was an eruptive event, it was less powerful than the classical 1996 and 1990 "outbursts" but otherwise similar in spectral shape (temperature) to the event seen in 1990.

Although the actual events on Io were undoubtably complex, a simplified calculation assumes all the changes in emission between Aug. 24 and Aug 26 occurred at one location (351° W, 22° N). Conceptually we are combining the multiple hotspots seen by Spencer *et al. in the* hemisphere and looking at their aggregate change, assuming that the other volcanic areas on Io in this hemisphere did not change between the two days.

Figure 3 shows the August 26, 1995 data from Spencer *et al.* (1997). Three components are required to achieve a reasonable match to the data. One component is a combination of Loki, other minor sources in the same hemisphere, and the 200 K, presumably older, source at 9507A (dash-dot-dash in Figure 3). The other two temperature components are for the spot located at 3510 W, 22° N. A single graybody (with emissivity≈0.9) spectrum could not be added to this base emission and match the data. Two graybodies provide a reasonable tit however: one with a temperature of 1500 K and a radius of 0.3 km, and the other with a temperature of 410 K and a radius of 22 km. Comparing this with the model values for two days earlier (2.2 km radius, 1500 K temperature), we infer a sequence qualitatively consistent with what we have deduced for the larger 1990 eruption from models of cooling lava flows (Carr 1986, Davies 1996, Howell *et* al, 1997). The decrease in the equivalent radius of 2.2 km to 0.3 km for the 1500 K spot could happen either because the volcanic eruption was ending and the effusion rate was dropping or because lava tubes had formed. This scenario is plausible given previous studies of such events on Io.

A calculation similar to that done in Blaney *et al. (1995)* for the 1990 outburst can be done. If the entire model area at 410 K (1.5 x 10^3 km^2) formed in the roughly 48 hours between observations, this would imply an average resurfacing rate of31 $km^2 hr^{-1}$ or 8.7x $10^3 m^2 s^{-1}$. Assuming a lava flow thickness of 10 meters, this implies an effusion rate of 8.7x104 $m^3 s^{-1}$, about half that found for the 1990 outburst. This effusion rate is the same order of magnitude as estimates of large eruptions on the moon (e.g., Hulme and Fielder 1977, Head and Wilson, 1981) and the Earth (Baloga and Spudis 1992).

IV. Discussion

Time scales and magnitudes of variability

The 1.7 to 2.2 μm emittances reported for 1995 are within the range expected from previous apparitions. Greater variability at the shorter wavelengths, compared to 8.7 and 20 μm, is probably the result of the physics of black body emission as a function of temperature combined with the fact that very hot lava cools quickly if not continuously replenished. This spectral region is very sensitive to relatively small changes in the temperature of hot lava, As suggested by Blaney *et al.* (1995), the 1 to 5 μm in-eclipse imaging is now detecting Io's widespread ‘normal" activity that must be occurring nearly continuously to support the relatively steady level of the mid-infrared flux documented in Veeder *et* al. (1994). The Spencer *et al.* and Silverstone *et al.* short wavelength data confirm that small high temperature eruptions occur frequently. We conclude that 1995 was typical for Io, in terms of overall observed variability in the volcanic sources based on the expected variability from extrapolating the Veeder *et al.* models. Higher power “outbursts” such as those seen in 1986 and 1990 should produce 1 to 3 μm emittances -100 times higher than those observed in 1995. These large events presumably occur less frequently and last only for brief periods (Johnson *et al.* 1986, Veeder *et al .1994,* Blaney *et al.* 1995). Longer wavelength emission changes are smaller and occur over longer periods (months to years).

This range of variability may result from a continuous distribution of high temperature events of various sizes, with the more energetic “outbursts” occurring less frequently. Rather than the traditional descriptions of “outbursts” and “normal” activity, we can now view Io’s volcanism as a continuum of high temperature events of varying power output and duration. Events can be characterized by their temperature, size, power, location, and the time period over which they have been active.

Lava composition

The exact composition of the high temperature lavas on Io is unknown. However, as argued by Carr (1986), Io’s surface morphology, bulk density, and likely geochemistry are highly suggestive of silicates, The documented presence of events with temperatures well above the point of sulfur (Johnson et al. 1988, Veeder *et al.* 1994, Blaney *et al,* 1995, Goguen *et al.* 1996, McEwen *et al.* 1997, Spencer *et al., 1997,* Lopes-Gautier *et al.* 1997, Davies *et al.* 1997, Stansberry *et al.* 1997), now eliminates sulfur as the "universal" lava. However, other lava compositions, including sulfur, cannot be excluded for lower temperature anomalies

At least some of the lower temperature anomalies are clearly associated with previous high temperature events. Our modeling of the observed fluxes and their changes between Aug. 24 and Aug. 26 provides yet another example of a high temperature (i.e. silicate lava) eruption associated with a larger cooler region. The 1990 outburst for instance was also seen to have a temperature well above the boiling point of sulfur then to cool rapidly during a period of about 2 hours (Veeder *et al. 1994,* Blaney *et al. 1995,* Davies 1996). Even on Earth, active lava flows are rarely observed at their magmatic temperatures (Flynn and Mouginis Mark, 1992) . High temperature lavas, in general, are expected to cool rapidly (Carr 1986, Davies 1996, Howell 1997). The observed frequency of occurrence of high temperature events suggests that they could well support the entire observed population of cooler temperature anomalies. It may be more productive to consider sulfur flows on Io in the eontext of remobilization of existing sulfur deposits, which is the source of terrestrial sulfur flows (Greeley *et al. 1990)*

In addition several lines of argument suggest relative stability of volcanic centers during the current epoch. The addition of only one new hotspot since 1983 and the continuous (through variable) activity at Loki during the thirteen years of the JPL-NASA/IRTF monitoring program, implies that the locations of volcanic activity can be stable for periods on the order of decades. Hot spots identified by Spencer *et al.* (1990,1 992,1 994,1997) also show stability in that their locations appear to be fixed. Recent Galileo NIMS and SS1 data have also shown present activity at locations previously identified as thermal anomalies in Voyager data and/or by ground W observers (Lopes-Gautier *et al.,* 1997, McEwen *et al.* 1997). Repeated eruption of magma at the same location inevitably produces adjacent, lower temperature thermal anomalies over time. Magma brought to the surface through caldera or fissure eruptions will form some type of lava flow over time. Active lava lakes have flows associated with them either when the lake overflows or through the formation of lava tube systems. We conclude that tJre thermal activity seen on Io can be explained by the continuing resurfacing of Io with silicate lavas and the evolution of these volcanic eruptions.

Acknowledgements. The authors are visiting astronomers at the Infrared Telescope Facility which is operated by the Institute of Hawaii under contract from the National Aeronautics and Space Administration. We continue to appreciate the help and tolerance of the IRTF operators Charlie Kaminski, Dave Griep and William Golisch. We have benefited from discussions with many colleagues including Ashley Davies and John Stansberry. An anonymous GRL reviewer provided useful comments. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract with NASA.

References

Baloga, S.,and P. Spudis, Reconstruction of the dynamics of the 1800-1801 Hualalai eruption, *Lunar and Planetary Science XXIV,* 55-56, 1993.

Beckwith, S., N.J. Evans, E. E. Becklin and G. Neugebauer, Infrared observations of Monoceros R2, *Astrophys. J., 208, 390-395, 1976.*

Blaney, D. L., T. V. Johnson, D. L. Matson, and G. J. Veeder, Volcanic eruptions on 10: heat flow, resurfacing, and lava composition. Icarus, 113,220-225, 1995.

Carr, M. H., Silicate volcanism on Io, *J. Geophys. Res.*, **91,3521-3532, 1986.**

Davies, A., Io's volcanism- Thermophysical models of silicate lava compared with observations of thermal emission, *Icarus,* **124, 45-61, 1996.**

Davies *A .G., AS.* McEwen, R.M.C. Lopes-Gautier, L. Keszthyi, R. W.Carlson, and W.D. Smythe, Temperature and area constraints of the South Voland Volcano on Io from NIMS and Galileo SS1 instruments during the Galileo G1 Orbit, *Geophys. Res. Let.,* in press this issue, 1997.

Flynn, L. P and P. J. Mouginis-Mark, Cooling rate of an active Hawaiian lava flow from nightime spectroradiometery measurements, *Geophy. Res. Let.,* 19, 1783-1786, 1992.

Goguen,J. D., D. L. Blaney, G. J. Veeder, I). L. Matson, T. V. Johnson, 10's Mid-IR volcanic thermal emission at the Galileo epoch, *Bull. Am Astron. Sac., 27,* 1153, 1996.

Greeley, R. and B. D. Schneid, Magma generation *on* Mars: Amounts, rates and comparisons with Earth, Moon, and Venus, *Science,* 254,996-998, 1991.

Hanner, M. S., A.T. Tokunaga, G.J. Veeder and M.F. A'Hearn, Infrared photometry of the dust in comets, *Astron. J.* 89, 162-169, 1984.

Head, J. W., and L. Wilson, Lunar sinuous rille formation by thermal erosion: Eruption conditions, rates and durations, *Lunar and Planetary Science XII, 427429,* **1981.**

Howell, R.R., Thermal emission from lava flows on Io, Icarus, 127,439446, 1997.

Hulme, G. and G. Fielder, Effusion rates and rheology of lunar lavas, *Philos. Tram. R Sac. London, Ser. A., 285, 227-234, 1977.*

Johnson, T. V., G. J. Veeder, D. L. Matson, R. H. Brown, R. M. Nelson, and D. Morrison, 10: Evidence for silicate volcanism in 1986, Science, 242, 1280-1283, 1988.

Lopes-Gauteir, R., A. G. Davies, R. Carlson, W. Smythe, and L. Soderblom, Monitoring Io's volcanic activity using Galileo's Near Infrared Mapping Spectrometer, *Geophys. Res. Let.,* in press this issue, 1997.

Matson, D. L., G.A. Ransford, and T.V. Johnson, Heat flow from Io, *J. Geophys. Res.,* 86, 1664-1672, 1981.

McEwen *et al., SS1* observations of Io during the first half of the Galileo tour of Jupiter, *Lunar Planetary Science Conference XXVIII,* CD Rom published, 1997.

Morrison, D., and C. M. Telesco, Io: Observational constraints *on* internal energy and thermophysics of the surface, Icarus, 44, 226-233, 1980.

Silverstone, M. D., E. E. Becklin, K. I. Tsetsenekos, K Photometry of 10 in eclipse during 1995, *Bulletin of the American Astronomical Society, 27,* 1162-1163, 1995.

Spencer, J. R., M. A. Shure, M. E. Ressler, J. D. Goguen, W. M. Sinton, D. W. Toomey, A. Denaults, and J. Westfall, Discovery of hotspots on 10 using disk-resolved infrared imaging Nature, 348, 618-621, 1990.

Spencer J., R. Howell, B. Clark, D. Classen, and D. O'Connor, Volcanic Activity on Io at the time of the Ulysses encounter, Science. 257, 1507-1510, 1992.

Spencer, J. R., B.E. Clark, L. M. Woodney, W.M. Sinton, and D. Toomey, 10 hot spots in 1991: Results from Europa occultation photometry and infrared imaging, *Icarus* 107, 195-208, 1994.

Spencer, J. R., J. A Stansberry, C. Dumas, D. Vakil, R. Pregler, M. Hicks, and K. Hege, A history of high-temperature Io volcanism at the start of the Galileo tour, *Geophys. Res. Let.*, in press, 1997. .

Stansberry, J. A, J. R. Spencer, and R. R. Howell, Violent silicate volcanism on Io in 19%, *Geophys. Res. Let.*, in press this issue., 1997.

Veeder, G. J., D. L. Matson, T. V. Johnson, D. L. Blaney, and J. D. Goguen, IO*s heat flow from infrared radiometry 1983-1993. *J. Geophys. Res.*, Planets 99, 17095-17162, 1994.

'Diana L. Blaney, Jet Propulsion Laboratory, MS 183-501,4800 Oak Grove Blvd. Pasadena, Ca, 91109.
(email: Diana. L.Blaney @jpl.nasa.gov)

Glenn J. Veeder, Jet Propulsion Laboratory, MS 183-501, 4800 Oak Grove Blvd,Pasaden%C%91109.
(email: gveeder@scn1 .jpl.nasa.gov)

Dennis L. Matson, Jet Propulsion Laboratory, MS 183-501,4800 Oak Grove Blvd. Pasadena, Ca, 91109.
(email: Dennis. L.Matson @jpl.nasa.gov).

Torrence V. Johnson, Jet Propulsion Laboratory, MS 183-S01, 4800 Oak Grove Blvd. Pasaden%Ca,91109.
(email: tjohnson@jpltvg.jpl. nasa.gov).

Jay D. Goguen, , Jet Propulsion Laboratory, MS 183-501, 4800 Oak Grove Blvd. Pasadena, Ca, 91109.
(email: jdg@scn1 .jpl.nasa.gov) .

John Spencer, Lowell Observatory, 1400 Mars Hill Rd., Flagstaff, AZ 860001. (email: spencer@lowell.edu)

(Received: April 5, 1997; revised: August 18, 1997; accepted: August 27, 1997)

BLANEY ET AL: IO'S THERMAL ANOMALIES FROM 1 TO 20 μm

BLANEY ET AL: 10'S THERMAL ANOMALIES FROM 1 TO 20 μm

Table 1. 1995 Model Hot Spot Location, Area. and Temperatures. After Veeder et al. 1994, based on Goguen et al. 1996 data.

	R	T (K)	Power 12	R	T (K)	Power 12
Loki 1	12	525	1.76	10	525	1.22
Loki 2	15	300	0.29	20	400	1.64
Loki 3	520	150	21.95	200	180	6.73
Pele 1	12	500	1.44	12	500	1.44
Pele 2	550	150	24.55	500	150	20.29
Colchis 1	12	500	1.44	10	500	1.00
170° w 1	7	500	0.49	9.5	525	1.10
170" w 2	450	145	14.35	475	150	18.30
80" W 1	10	610	2.22	9.5	610	2.00
80" W 2	525	160	28.95	450	155	1.87
9507A-1	0	0	0	3.75	1000	2.19
9507A-2	0	0	0	225	200	12.98

Figure 1. Io's thermal emission at 4.8 (M), *8.7,* and 20 (Q) μm as a function of orbital longitude from Goguen et al. 1996. Data are shorn for 2 complete orbital lightcurves obtained during 11-16 June 1995 UT (open squares) and 17-24 August 1995 UT (solid circles). A complete description of the observations, reduction and analysis techniques can be found in Veeder ***et al.*** (1994). The 1995 data are modeled using the method described in Veeder ***et al.*** 1994 with thermal anomalies at fixed locations and variable areas and temperatures. The June 1995 model is shown as a solid line and the August 1995 model is shown as a dashed line. Solid circles at -20" W Longitude for 8.7 and 20 μm not matching models are eclipse observations for Aug. 22.

Figure 2. Comparison of recent observations with model calculations for 1983 to 1993. 1-5 μm eclipse observations from by Silverstone et al. 1995 and Spencer et al. 1997 are compared to the models for each apparition from 1983 to 1993 (Veeder et al. 1994) calculated for these wavelengths. The two "outbursts" discussed in Veeder et al. 1994 are also shown and labeled with the year they occurred (i.e. 1986, and 1990a (beginning of the night) 1990b (end of night)). Models for 1995 June and August Goguen et al. radiometry noted with dark lines and Spencer ***et al. data*** for Aug. 26, 1995 also noted.

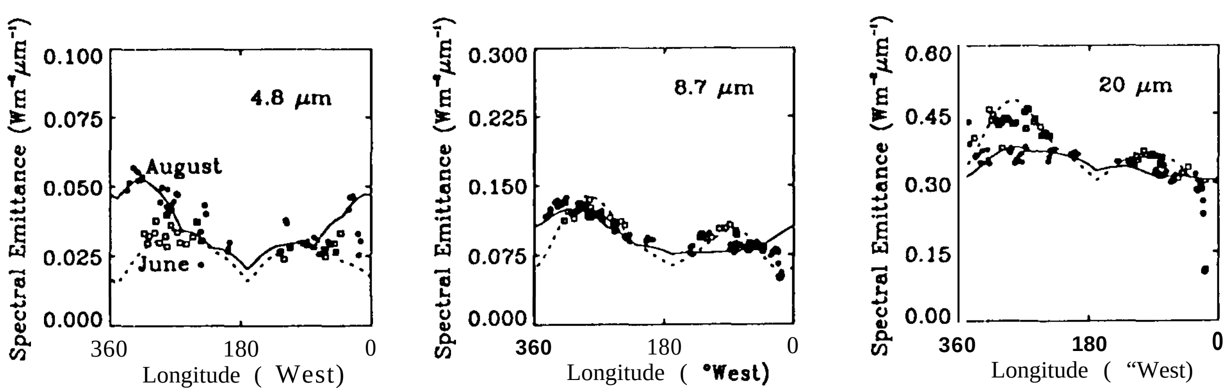
Figure 3. Thermal Model for Aug. 26, 1995. Data is from Spencer et al. 1997. (X's) are modeled with 3 thermal components (solid line). One component is a combination of Loki, other minor sources in the same hemisphere, and the presumably older 200 K source at this location(dash-dot-dash). Two thermal components are then added, One with a 1500 K and a radius of 0.3 km (dashed line), and the other with a temperature of410 K and a radius of 22 km (dotted line).

Figure 1. Io's thermal emission at 4.8 (M), 8.7, and 20 (Q) μm as a function of orbital longitude from Goguen et al. 1996. Data are shown for 2 complete orbital lightcurves obtained during 11-16 June 1995 UT (open squares) and 17-24 August 1995 UT (solid circles). A complete description of the observations, reduction and analysis techniques can be found in Veeder ***et al. (1994).*** The 1995 data are modeled using the method described in Veeder ***et al.*** 1994 with thermal anomalies at fixed locations and variable areas and temperatures. The June 1995 model is shown as a solid line and the August 1995 model is shown as a dashed line. Solid circles at -20" W Longitude for 8.7 and 20 μm not matching models are eclipse observations for Aug. 22.

Figure 2. Comparison of recent observations with model calculations for 1983 to 1993. 1-5 μm eclipse observations from by Silverstone et al. 1995 and Spencer et al. 1996 are compared to the models for each apparition from 1983 to 1993 (Veeder et al. 1994) calculated for these wavelengths, The two "outbursts" discussed in Veeder et al. 1994 are also shown and labeled with the year they occurred (i.e. 1986, and 1990a (beginning of the night) 1990b (end of night)). Models for 1995 June and August Goguen et al. radiometry noted with **dark** lines and Spencer ***et al. data*** for Aug. 26, 1995 also noted.

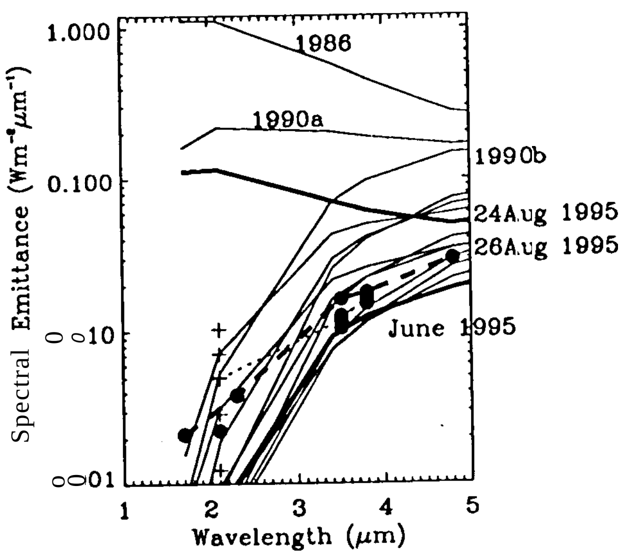
Figure 3. Thermal Model for Aug. 26, 1995. Data is from Spencer et al. 1997. (X'S) are modeled with 3 thermal components (solid line). One component is a combination of Loki, other minor sources in the same hemisphere, and the presumably older 200 K source at this location(dash-dot-dash). Two thermal components are then added. One with a 1500 K and a radius of 0.3 km (dashed line), and the other with a temperature of 410 K and a radius of 22 km (dotted line).

Fig 1.



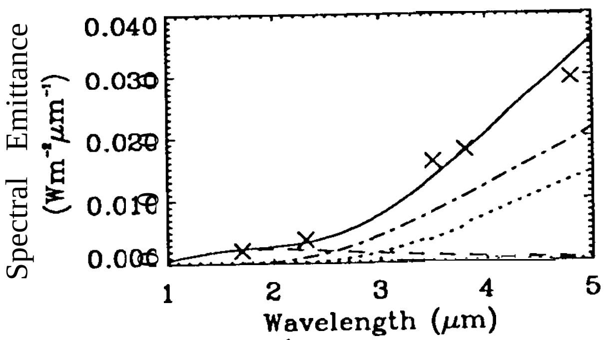
Spectral Emittance (Wm⁻²μm⁻¹)
0.100
0.075
0.050
0.025
0.000
4.8 μm
August
June
360
180
0
Longitude (West)
0.300
0.225
0.150
0.075
0.000
8.7 μm
Longitude (°West)
0.60
0.45
0.30
0.15
0.00
20 μm
Longitude ("West)

Fig 2.



1.000
0.100
0.010
0.001
Spectral Emittance (Wm⁻²μm⁻¹)
1986
1990a
1990b
24Aug 1995
26Aug 1995
June 1995
1
2
3
4
5
Wavelength (μm)

Figure 3



Spectral Emittance
(Wm$^{-2}\mu$m^{-1})
0.040
0.030
0.020
0.010
0.000
1
2
3
4
5
Wavelength (μm)